Research Plan

for

Proposed Research

in

Grid Communication using WSN

under the

guidance of

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1. INTRODUCTION

The existing U.S. electric power grid was built over 100 years ago with the aim to deliver electricity from large power stations to customers [1]. In the past decade, blackouts and grid failures have become a noticeable problem, which can cause great damages and inconvenience to people's daily life [2]. There is thus a need to make the current electricity network more reliable, efficient, secure, and environmentally friendly. This can be achieved by the next-generation power grid, i.e., the smart grid, which is characterized by a two-way flow of electricity and information, creating an automated, widely distributed energy delivery network. With an emerging smart grid, various intelligent and automated applications can be enabled. These applications are such as home/building automation, automated meter reading, distribution automation, outage and restoration management and integration of electric vehicles [3]. Today's electric power grid has become a complex network of networks, comprising both power and communication infrastructures, and several thousands of intelligent electronic devices (IEDs) [4]. Communication networks provide necessary infrastructure, allowing a utility to manage these devices from a central location. In the smart grid environment, heterogeneous communication technologies and architectures are involved. Communication networks should meet specific requirements, i.e., reliability, latency, bandwidth and security, depending on smart grid applications. The complexity of the smart grid may lead to difficulties in choosing appropriate communications networks as many parameters and different requirements must be taken into account depending on applications and utility expectations. The capability and requirements that the smart grid needs from both power and communications perspectives are provided in [5]. The summary of application characteristics and traffic requirements of the communication infrastructure in the smart grid [6], while a brief survey of selected transmission grid applications in terms of their bandwidth and latency requirements [7]. Although existing wired and wireless communication technologies can be applied to the smart grid, establishing smart grid standards and protocols is an urgent issue for some devices, i.e., smart meters [8]. In the literature, smart grid technologies and standards are discussed to provide an overview of the smart grid paradigm and integration of different communication technologies [9,10]. Some studies focus on a specific standard or communication technologies, i.e., smart metering [11], power line communication (PLC) [12], and wireless communication [13,14]. Additionally, selection of communication technologies for transmission-level applications has been addressed in [16]. These are various structures of smart grid in terms of typical payload, data sampling requirements, as well as latency and reliability requirements for smart grid applications deployed in a Home Area Network (HAN), Neighborhood Area Network (NAN) and Wide-Area Network (WAN). Based on selected smart grid projects around the world, various communication technologies that have been implemented to support real-world smart grid applications are available. The objective of this report is to provide an introduction of communication technology requirements for different smart grid applications implemented at generation, transmission, distribution and customer levels. The smart grid is an interactive platform, consisting of a power system layer, a control layer, a communication layer, a security layer and an application layer. This architecture represents how a smart grid can be implemented. In general, a smart grid comprises: (1) a power system layer, which refers to power generation, transmission, distribution and customer systems; (2) a power control layer, which enables smart grid monitoring, control, and management functions; (3) a communication layer, which allows two-way communications in a smart grid environment; (4) a security layer, which provides data confidentiality, integrity, authentication

and availability; and (5) an application layer, which delivers various smart grid applications to customers and utilities based on an existing information infrastructure.

1.1 PROBLEM DEFINITION

The implementation of wireless sensor networks in a smart grid has many challenges like, resource limitations, high end to end delay, high power consumption and low throughput. The smart grid should have long network lifetime and reliable security mechanism too. The real time monitoring and data transmission requires maximum coverage of the smart grid area and minimum delay, so that the messages regarding damage and intrusion can be received in the real time to prevent any major loss to the infrastructure. The other very important issue is the security of data. The meter reading, usage of power and un-authenticated access to the information. The communication network should have efficient algorithms, tools or softwares to prevent the hackers to access the information. The main areas of concern in this report are the designing and implementation of efficient routing algorithms to find the minimum cost paths, the selection of trust nodes to maximize the coverage area, increasing network lifetime, reducing end to end delay and increasing throughput.

1.2 EXPECTED OUTPUTS

The expected outputs are end to end delay, coverage rate, tolerance rate, throughput and network lifetime. The end to end delay constitutes of D_{PT} is the packet transferring delay, D_P is the processing delay, D_Q is the queuing delay, and D_{Pr} is the propagation delay. The first three delays are due to nodes and the last is due to edges. The formula of two delays are depicted as follows: D_T = (Number of bits)/ Data rate, D_{Pr} = (Distance of nodes)/ Data rate.

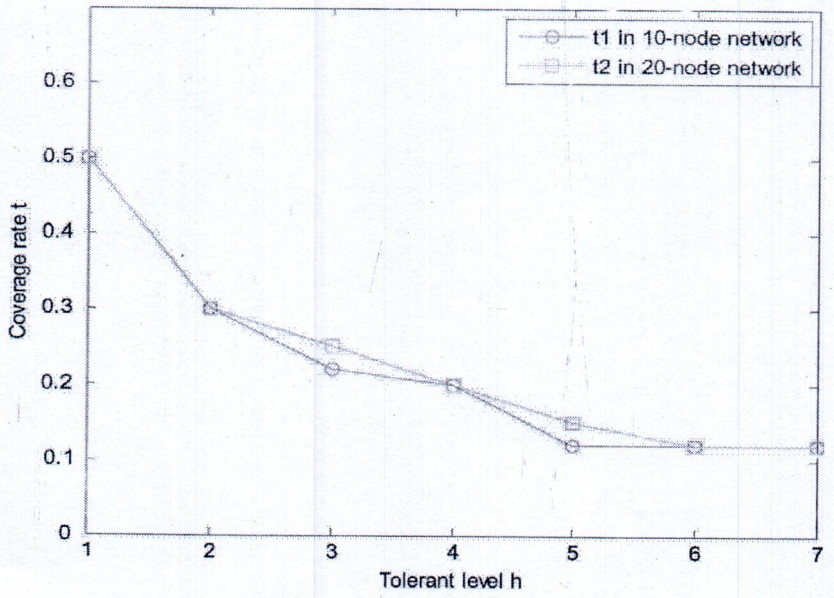

Fig. 1. The graph between tolerant level and coverage rate.

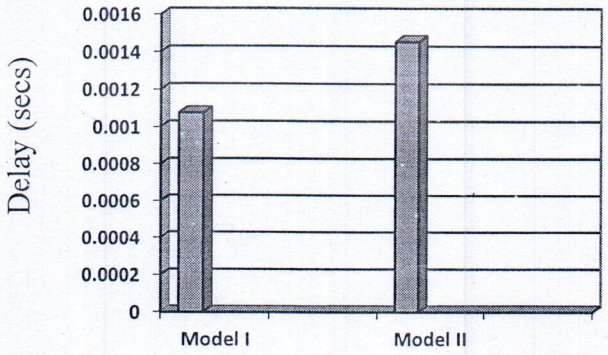

Fig. 2. End to end delay

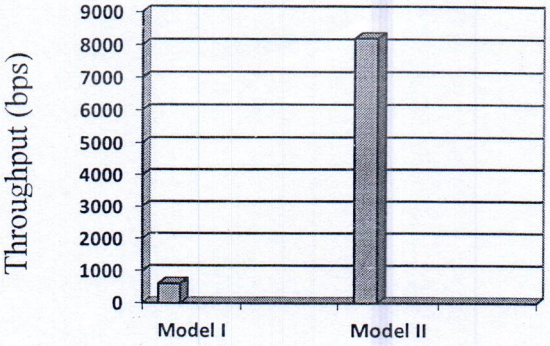

Fig. 3. Throughput

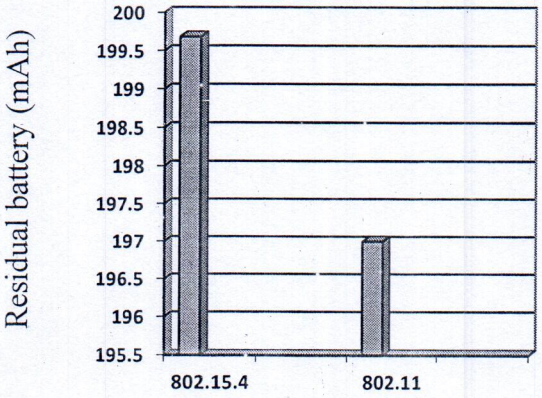

Fig. 4. Residual battery

Table I. Simulation Results

S. No.	Parameter	Model I	Model II
1	Delay (secs)	0.001076	0.001455
2	Throughput (bps)	608	8192
3	Residual battery (mA.h)	199.68	197

3. RESEARCH REVIEW

The present research is based on the designing and implementation of efficient topologies to increase the network coverage and minimizing the number of trust nodes to save the battery power. The reduction in delay and consumption of battery power increases the network lifetime. The imposed communication network brings more vulnerabilities to the evolving smart grid. Therefore, defensive techniques such as intrusion detection will need to be deployed in this already complicated system. Deployment and runtime cost due to the defensive trust systems will affect the original function of smart grid system without careful planning and design. In particular, the set packing algorithm is used to optimize the placement of the trust nodes of the defensive system in the multiple layer architecture of the smart grid. After the trust nodes are placed, a trust node aware optimal routing algorithm is used to find the least cost routing in the communications of the nodes. Also, an algorithm to identify new trust node(s) is presented to address the fault tolerance requirement of the smart grid system. The research papers on the deployment of efficient smart grids [1][2], survey on the communication architectures in smart grid [3][4] specifies the methodologies of deployment of smart grids. The application characteristics and traffic requirements of a smart grid communications networ [6].The variations of bandwidth and latency requirements for smart transmission grid applications [7].

The awareness about frame work and roadmap for smart grid interoperability standards [8] along with smart grid technologies: communication technologies and standards to understand the research challenges, solutions, and standardization activities [9][10]. The communication network requirements for major smart grid applications in HAN, NAN and WAN [11], power line communications and smart grid [12] and the implementation of demand response in a home area network [12] for proceeding towards a smart grid [13]. The concepts of design and implementation of an educational testbed for experiencing with industrial communication networks is specified in [16]. The research topics of interest based on real-time applications and industrial wireless sensor networks are covered in [17]18]. The algorithms to find out minimum cost path and minimizing the number of trust nodes to achieve maximum area coverage and minimum delay [19][20].

4. METHODOLOGY

Initially, the implementation of wireless sensor networks will be considered. The analysis of the simulation results will drive the research towards the improvement of parameters of interest. Like, a set packing algorithm has been applied for the optimization of the trust nodes placement . In the set packing problem, it is required that the network is partitioned into sub-networks by at least one trust node under the separation constraints. The elements in the networks can be seen as the nodes, edges, and the subsets partitioned by the constraints such as the number of hops between nodes. The objective of the set packing algorithm is to minimize the number of trust nodes as well as to maximize the intrusion detection rate. The network is modeled as a bidirectional graph, $G= (V, E)$, in which V is the set of nodes of the network and E is the set of edges connecting with the nodes. Every node in V can be considered as a router or a component of the smart grid in the three-layer architecture with the capability as the trust node. And the capability can be enabled when the node is selected as the trust node; otherwise it remains as a normal communication node. The set packing algorithm is applied to check each node as the potential trust node candidate. The communication between two nodes is directly available without going through any other nodes if and only if these two nodes are directly connected to each other. After finding the trust nodes for the whole SGDIDS system, an optimal routing algorithm is applied to increase the cost efficiency. By applying the optimal routing algorithm, the most effective communication path can be identified based on the cost of links between nodes, by distributing the bandwidth and delay across the network. The algorithms for increasing the efficiency of wireless sensor networks in Home Area Network (HAN) are important. The simulation of smart grids based on various algorithms and the comparison of simulation results will be carried out to determine the crux parameters. The variation of important parameters to improve the network performance will lead the research.

The smart grid is an interactive platform, consisting of a power system layer, a control layer, a communication layer, a security layer and an application layer. See Fig. 1. This architecture represents how a smart grid can be implemented. In general, a smart grid comprises: (1) a power system layer, which refers to power generation, transmission, distribution and customer systems; (2) a power control layer, which enables smart grid monitoring, control, and management functions; (3) a communication layer, which allows two-way communications in a smart grid environment; (4) a security layer, which provides data confidentiality, integrity, authentication

and availability; and (5) an application layer, which delivers various smart grid applications to customers and utilities based on an existing information infrastructure.

<table>
<tr><td colspan="4">Smart Metering and Grid Applications</td><td colspan="3">Customer Applications</td><td>Application Layer</td></tr>
<tr><td colspan="7">Authentication, Access Control, Integrity Protection, Encryption, Privacy</td><td>Security Layer</td></tr>
<tr><td colspan="2">Wi-MAX, Cellular, Fiber Optics</td><td colspan="2">RF Mesh, PLC, DSL, Coaxial Cable</td><td colspan="3">ZigBee, WiFi, Z-Wave, Home Plug</td><td rowspan="2">Communication Layer</td></tr>
<tr><td colspan="2">WAN</td><td colspan="2">NAN/FAN</td><td colspan="3">HAN/BAN/IAN</td></tr>
<tr><td>PMUs</td><td>Cap Banks</td><td>Switches</td><td>Sensors</td><td>Meters</td><td>Transformers</td><td>Storage</td><td>Power Control Layer</td></tr>
<tr><td colspan="3">Power Transmission Generation</td><td colspan="2">Power Distribution</td><td colspan="2">Customers</td><td>Power System Layer</td></tr>
</table>

Fig. 1. The system multi-layer architecture of smart grid.

Smart grid is a platform consisting of different domains, including generation, transmission, distribution, customers, service providers, operations and markets, to enable various applications. The generation domain is responsible for generating electricity from other forms of energy, e.g., fossil fuels, water, wind, solar radiation and geothermal heat. The transmission domain is responsible for transferring of electrical power from generation sources to distribution systems over long distances through multiple substations. The distribution domain is the electrical interconnection between the transmission and the customer domains. It distributes electricity from/to customers. A comparison of various communication technologies that can support smart grid applications in terms of data rate and coverage distance is presented in Table 1. As wireless technologies provide lower installation cost, more rapid deployment, higher mobility and flexibility than its wired counterparts, wireless technologies are recommended in most of the smart grid applications. Smart grid is a platform consisting of different domains, including generation, transmission, distribution, customers, service providers, operations and markets, to enable various applications. The generation domain is responsible for generating electricity from other forms of energy, e.g., fossil fuels, water, wind, solar radiation and geothermal heat.

Table 1. Comparison of communication technologies for the smart grid.

S. No.	Technology	Standard /Protocol	Max. Theoretical Data rate	Coverage Range	Network		
					HAN	NAN	WAN
Wireless Communication Technologies							
1.	Z-Wave	Z-Wave	40 kbps	Up to 30 m	√		
2.	Bluetooth	802.15.1	721 kbps	Up to 100 m	√		
3.	ZigBee	ZigBee	250 kbps	Up to 100 m	√	√	
		ZigBee Pro	250 kbps	Up to 1600 m	√	√	
4.	WiFi	802.11x	2-6000 Mbps	Up to 100 m	√	√	
5.	WiMAX	802.16	75 Mbps	Up to 50 m		√	√
6.	Wireless Mesh	RF mesh, 802.11, 802.15, 802.16	Protocols	Deployment	√	√	
7.	Cellular	2G	14.4 kbps	Up to 50 km		√	√
		2.5G	144 kbps	Up to 50 km		√	√
		3G	2 Mbps	Up to 50 km		√	√
		3.5G	14 Mbps	Up to 50 km		√	√
		4G	100 Mbps	Up to 50 km		√	√
8.	Satellite	Satellite Internet	1 Mbps	Up to 100-6000 km			√

It is understood that a successful smart grid project starts with a well-designed communications network and systems architecture. Selecting the right communication technologies is the fundamental component of this success. In various real-world smart grid implementations to be discussed below, many different communication technologies are deployed. In practice, an electric utility chooses to implement communication technologies that best fit its requirements after having evaluated current system infrastructures, technology standards, application requirements, and future scaling requirements. Selected smart grid projects are discussed below with the emphasis on their communication aspects. This information is summarized in Table 2.

Table 2. Smart Grid projects from various countries.

S. No.	Organization	Region, Country	Applications		Technologies
1.	Austin Energy	Texas, USA	i. ii. iii. iv. v. vi.	AMI Meter Reading Pricing Distribution Automation Service switch operation Demand Response	Optical fiber and RF mesh network.
2.	AC Propulsion	California, USA	i.	Electric transportation	Cellular
3.	Eandis and Infrax	Flanders, Belgium	i. ii.	Advanced metering management (AMM) Meter reading	PLC, DSL, Cellular (GPRS)
4.	Acea Distribuzione	Rome, Italy	i. ii.	Advanced metering management (AMM) Meter reading	PLC, Cellular (GPRS)
5.	Public Power Corporation	Larissa, Greece	i.	Demand response	Wi-Fi, Broad Power Line (BPL)
6.	China Southern Power Grid	Southern China	i. ii. iii. iv.	AMI Meter Reading Pricing Demand Response	

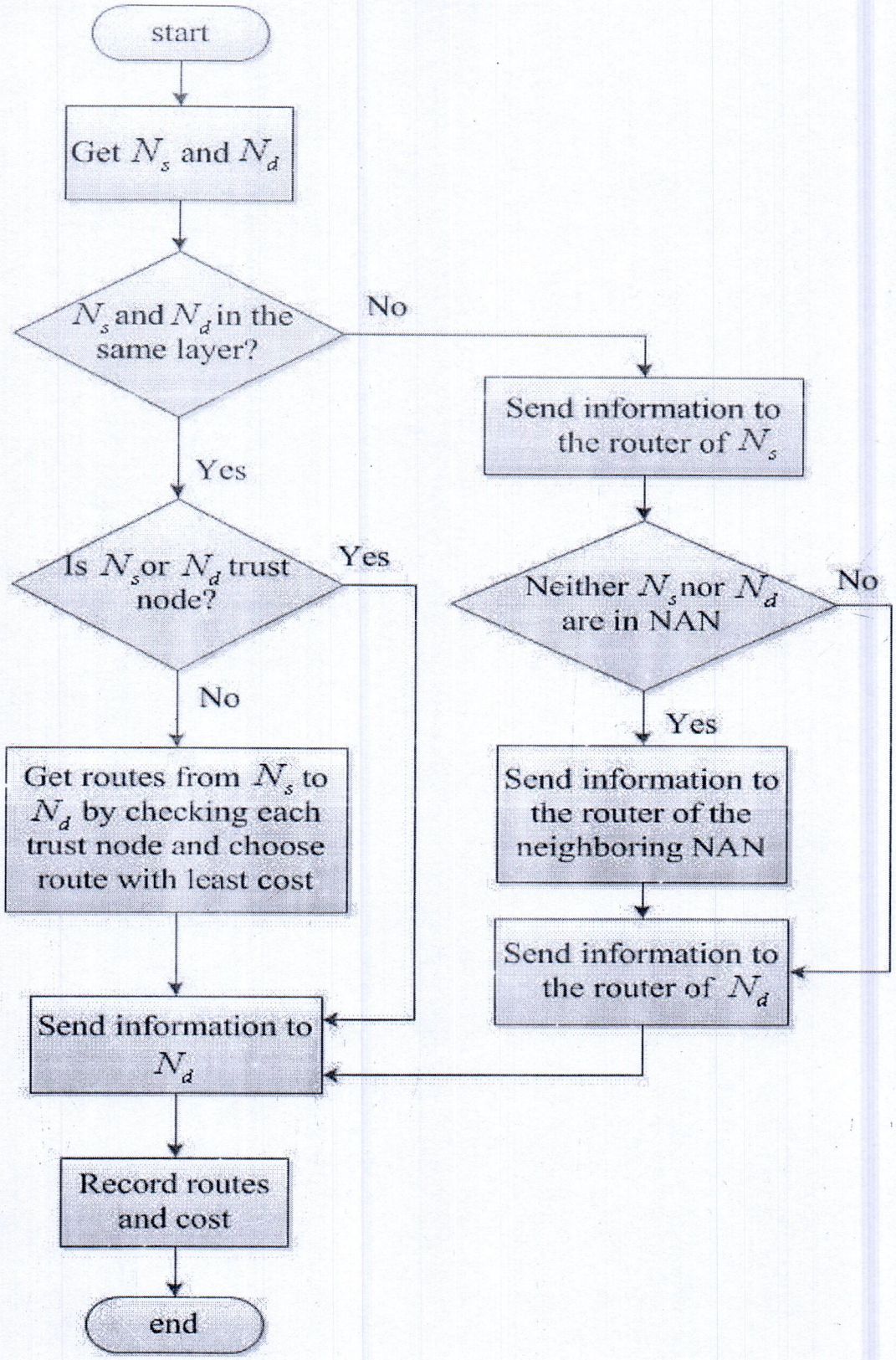
start
Get N_s and N_d
N_s and N_d in the same layer?
No
Yes
Send information to the router of N_s
Is N_s or N_d trust node?
Yes
No
Neither N_s nor N_d are in NAN
No
Yes
Get routes from N_s to N_d by checking each trust node and choose route with least cost
Send information to the router of the neighboring NAN
Send information to the router of N_d
Send information to N_d
Record routes and cost
end

Fig. 5. Flow chart of optimizing node placement using Set Packing algorithm.

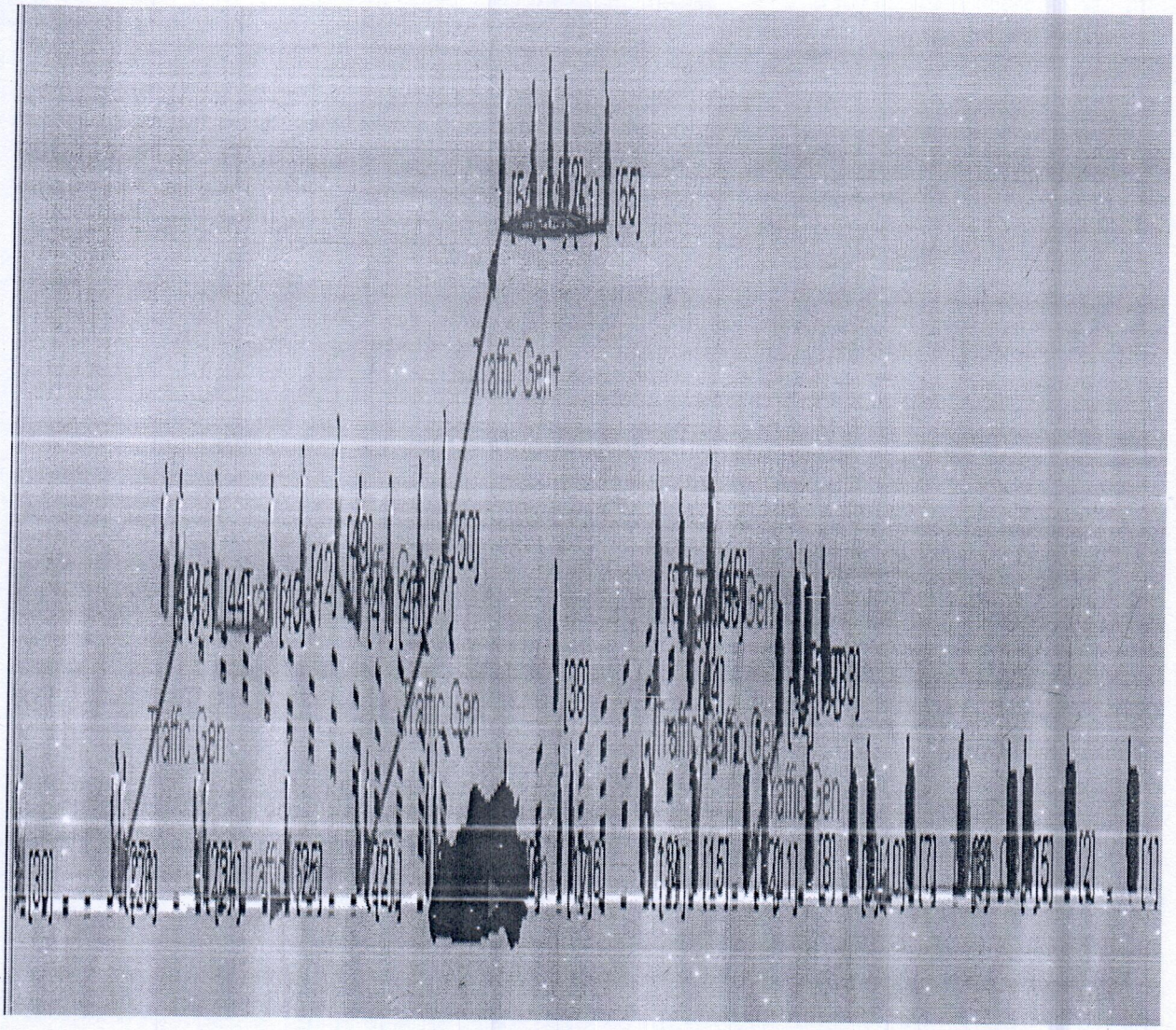

Fig. 6. Simulation Scenario

5. RESEARCH PLAN

The research plan proposed in this report is in infant state. The research plan for initial proceedings is given in Table 3. The topic of research will become more confined and precise as research proceeds further. The research plan aims at (1) Decreasing demand – The Electric Power Research Institute conducted a study that suggested Smart Grid technologies could reduce electricity consumption in the US by 10 to 15% by 2025. (2) Increasing efficiency and reliability –By flattening the consumption profile, the system can run much more efficiently and can respond more intelligently, with the potential, as previously mentioned, of running at 80% capacity instead of 50%.

Table 3. RESEARCH PLAN

S. No.	Research Work
1	Implementation of WSN communications in Smart Grid.
2	The performing of simulations on IEEE 802.15.4 – compliant wireless sensor nodes in power delivery systems and distribution systems to measure throughput, delay, and network lifetime.
3	The measurement of background noise , channel characteristics, and attenuation in the WSN smart grid networks.
4	The implementation of efficient topologies to design smart transmission grid.
5	The deployment of defensive techniques such as intrusion detection to secure critical infrastructure.
6	The development of methods of localization and communication routing optimization of trust nodes in smart grid network infrastructure.
7	The application of various algorithms to optimize (minimize) the placement of trust nodes.
8	The use of optimal routing algorithms to find the least cost routing between the communications of the nodes.
9	The study and implementation of mechanism supporting self-recovery in case that one or more trust nodes stop working.
10	The development and deployment of efficient node placement algorithms to avoid the cost of identifying the alternative trust nodes during runtime.
11	Trust system design optimization in smart grid network infrastructure.
12	The main aim is to reduce the end to end delay, consumption of battery power, number of trust nodes required for maximum coverage and increases in network lifetime and throughput in the wireless sensor network deployed in the Home Area Network (HAN) in Smart Grid.

6. BENEFITS OF THE RESEARCH

(i) The design and implementation of a WSN is constrained by the hardware resources of sensor nodes due to limited physical size, such as energy, memory, and processing. The implementation of efficient network topologies, routing algorithms and fault correction mechanisms will optimize the utilization these limited resources.

(ii) In power distribution environments, the connectivity and topology of the network may vary due to varying wireless link characteristics and node failures. In addition, sensor nodes may be subject to different environmental conditions which may cause sensor nodes to malfunction. The reliable and robust mechanisms will be developed to minimize the adverse effects of environmental variations on the communication network.

(iii) Variety of applications on WSN for smart grid will have different QoS requirements and specifications in terms of reliability, throughput and latency. The applications based on real time monitoring must have minimum delay and reliable message transmission scheme. The identification of various components and protocols to increase the reliability of the network is also of great concern ad will be considered.

(iv) The reduction of bit error rate as wireless links are location dependent and vary continuously due to noisy environment and obstructions, the bandwidth of wireless links depends on the interference level perceived at receivers, and high bit error rates are observed in communication. Therefore, it is very hard to meet QoS requirements in smart grid applications due to the varying characteristics of wireless links. The bit error rate observed in communication is from 1/100-1/1000000.

(v) The increase in security as security is an essential feature in the design of WSN-based smart grid applications in order to provide safe communication by preventing intrusion and denial of service (DoS) attacks.

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